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(54) **EFFICIENT TEXTURE COMPARISON**

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(51) **Int. Cl.**

G06K 9/62	(2006.01)
G06K 9/00	(2006.01)
G06F 21/32	(2013.01)
G06F 21/60	(2013.01)

(52) **U.S. Cl.**
CPC ***G06K 9/0008*** (2013.01); ***G06F 21/32*** (2013.01); ***G06F 21/602*** (2013.01); ***G06K 9/00006*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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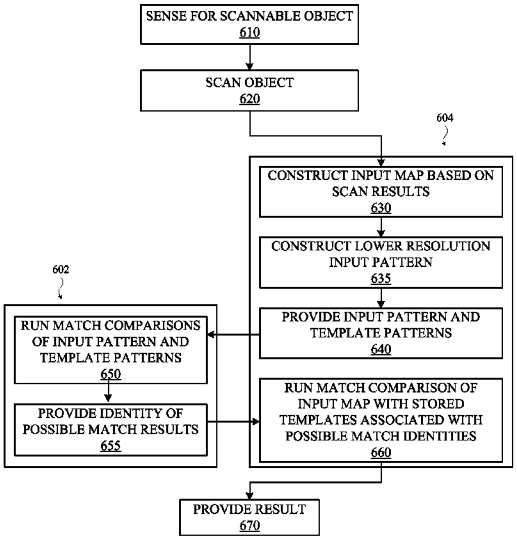
(57) **ABSTRACT**

A scannable object is sensed and scanned. A map is constructed based on the scan results. The map is compared to one or more stored templates. Results of the comparison are provided. In some implementations, a secured processor may construct the map and may provide reduced resolution (and/or other versions that contain less information) versions of the map and/or the stored templates to one or more other processors. The one or more other processors may determine a match-set based on matching between the reduced resolution map and stored templates. The secured processor may then identify whether or not a match exists between the map and any stored template based on the match-set.

19 Claims, 6 Drawing Sheets


SENSE FOR SCANNABLE OBJECT 610
SCAN OBJECT 620
604
CONSTRUCT INPUT MAP BASED ON SCAN RESULTS 630
CONSTRUCT LOWER RESOLUTION INPUT PATTERN 635
602
RUN MATCH COMPARISONS OF INPUT PATTERN AND TEMPLATE PATTERNS 650
PROVIDE INPUT PATTERN AND TEMPLATE PATTERNS 640
PROVIDE IDENTITY OF POSSIBLE MATCH RESULTS 655
RUN MATCH COMPARISON OF INPUT MAP WITH STORED TEMPLATES ASSOCIATED WITH POSSIBLE MATCH IDENTITIES 660
PROVIDE RESULT 670

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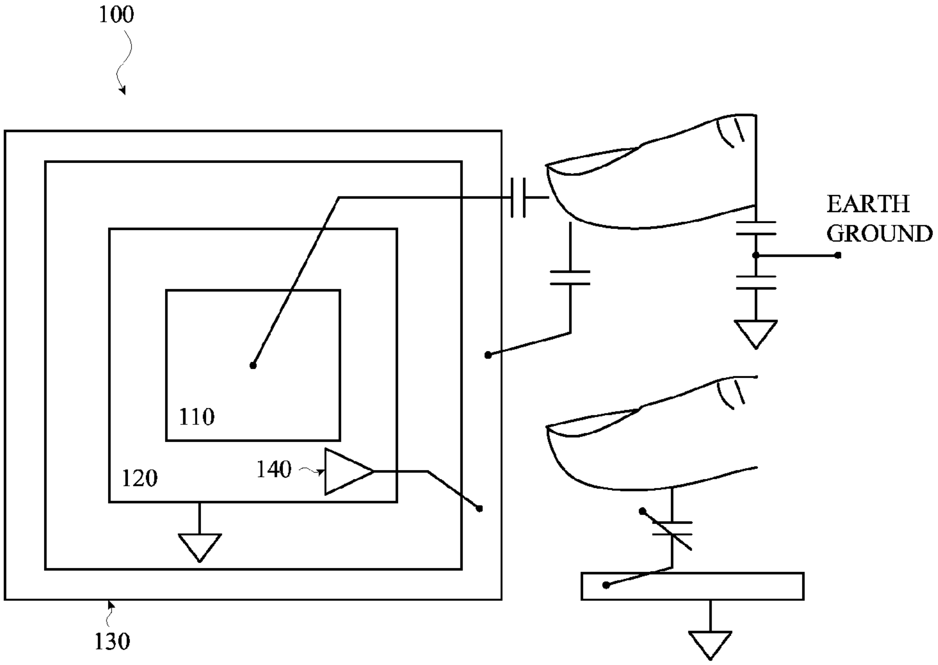

FIG. 1

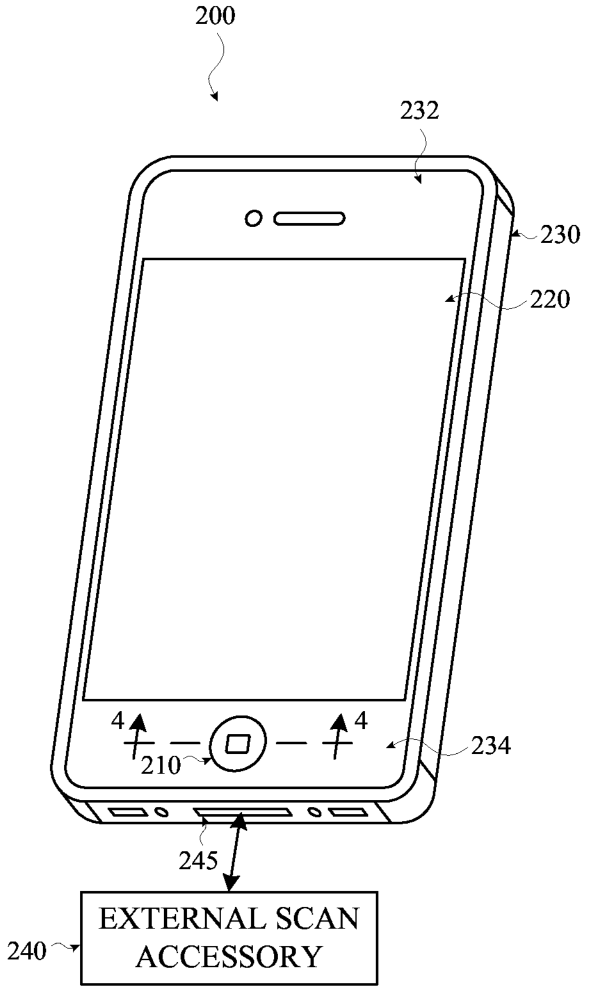

FIG. 2

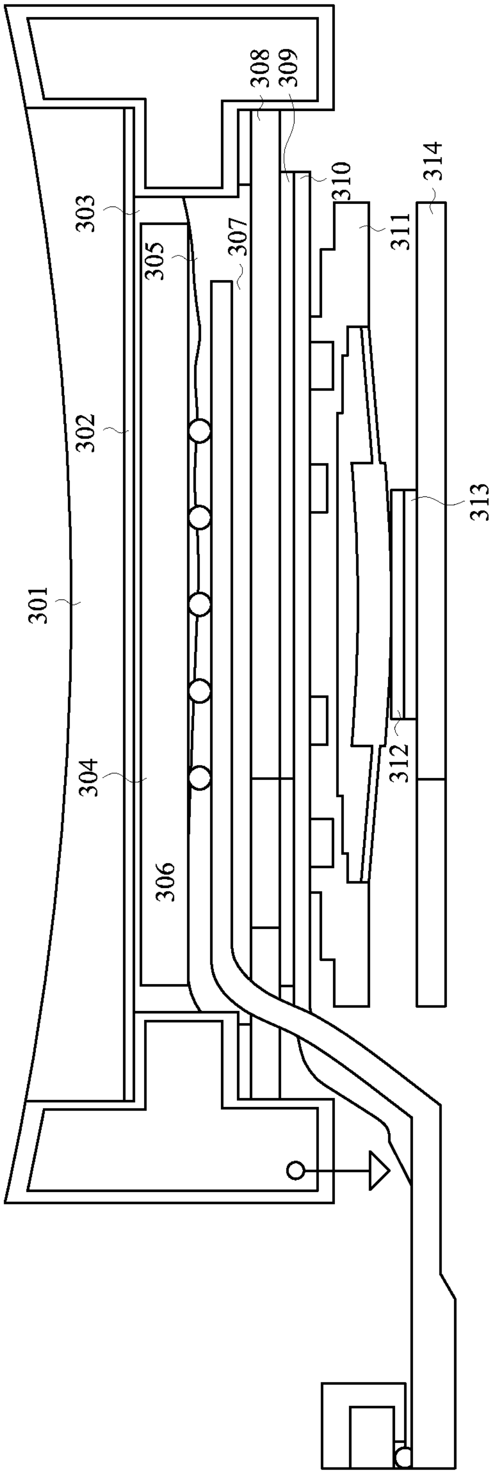

FIG. 3

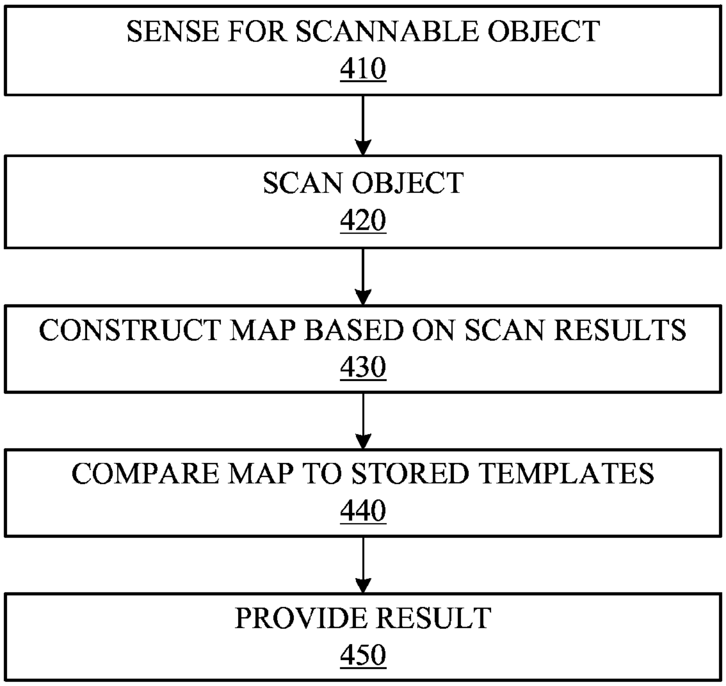
SENSE FOR SCANNABLE OBJECT
410
SCAN OBJECT
420
CONSTRUCT MAP BASED ON SCAN RESULTS
430
COMPARE MAP TO STORED TEMPLATES
440
PROVIDE RESULT
450

FIG. 4

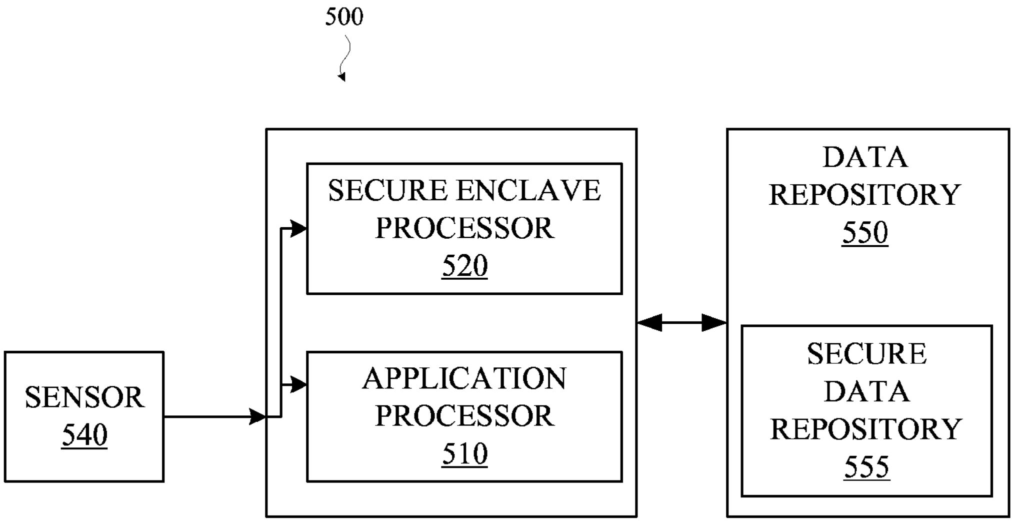
500
SECURE ENCLAVE PROCESSOR 520
APPLICATION PROCESSOR 510
SENSOR 540
DATA REPOSITORY 550
SECURE DATA REPOSITORY 555

FIG. 5

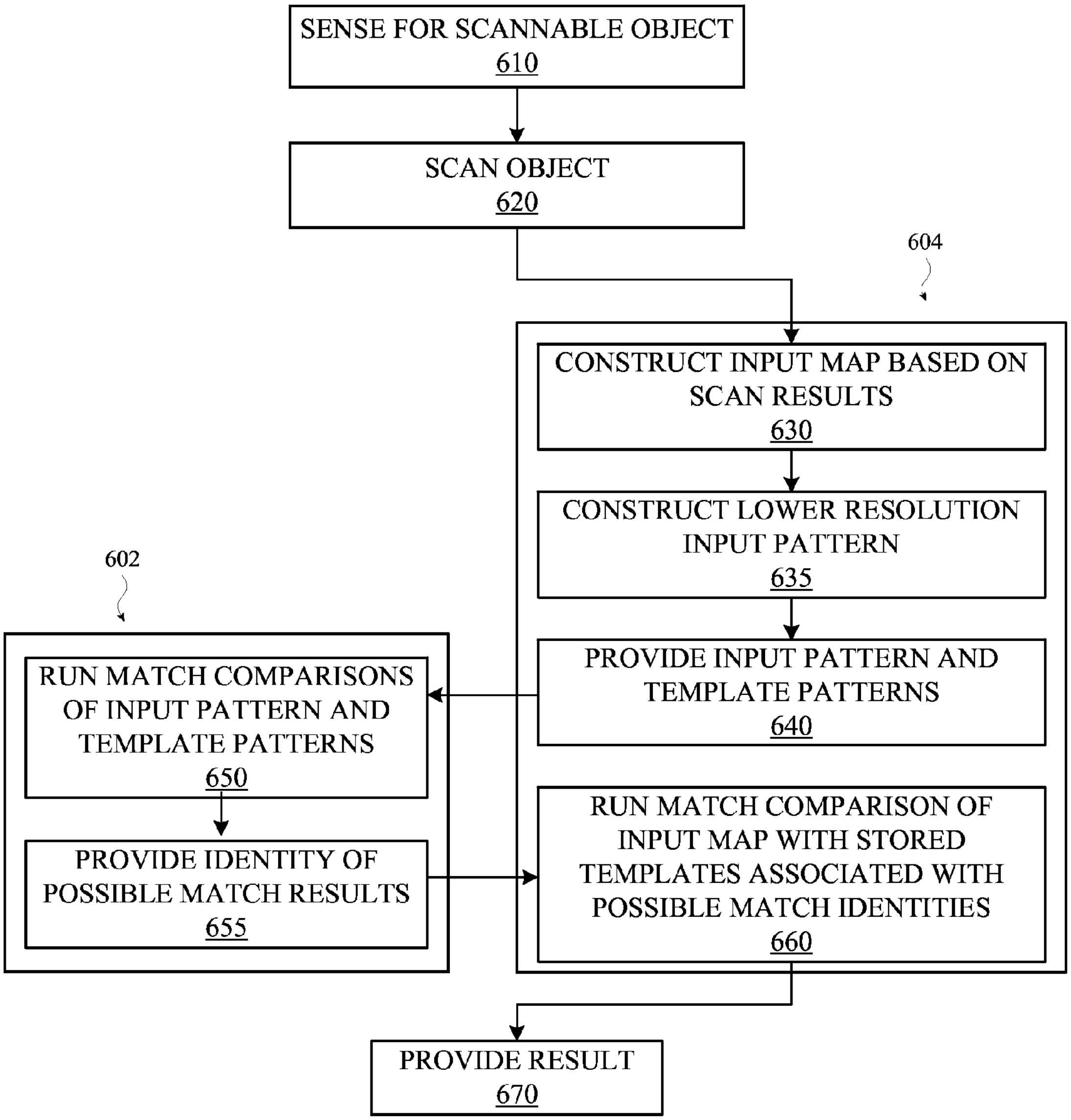
SENSE FOR SCANNABLE OBJECT
610
SCAN OBJECT
620
604
CONSTRUCT INPUT MAP BASED ON SCAN RESULTS
630
CONSTRUCT LOWER RESOLUTION INPUT PATTERN
635
PROVIDE INPUT PATTERN AND TEMPLATE PATTERNS
640
602
RUN MATCH COMPARISONS OF INPUT PATTERN AND TEMPLATE PATTERNS
650
PROVIDE IDENTITY OF POSSIBLE MATCH RESULTS
655
RUN MATCH COMPARISON OF INPUT MAP WITH STORED TEMPLATES ASSOCIATED WITH POSSIBLE MATCH IDENTITIES
660
PROVIDE RESULT
670

FIG. 6

EFFICIENT TEXTURE COMPARISON

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims the benefit under 35 U.S.C. §119(e) to U.S. Provisional Patent Application No. 61/649,210, which was filed on May 18, 2012, and entitled "Efficient Texture Comparison," which is incorporated by reference as if fully disclosed herein.

TECHNICAL FIELD

Embodiments described herein relate generally to a device and process for efficient texture pattern comparison and matching, and more specifically to fingerprint matching on a portable device.

BACKGROUND DESCRIPTION

Fingerprint sensing technology has become widespread in use and is often used to provide secure access to sensitive electronic devices and/or data. Generally, capacitive fingerprint sensors may be used to determine an image of a fingerprint through measuring capacitance through each pixel of a capacitive sensor. The higher the capacitance, the nearer the surface of an adjacent or overlying finger to the pixel. Thus, fingerprint ridges provide a higher capacitance in an underlying pixel than do fingerprint valleys. There are other types of fingerprint sensors, such as optical sensors.

Typically, fingerprint sensors have been tied to relatively powerful computers, such as PCs or laptops, or incorporated in specialty devices specifically designed for fast processing and sufficient battery life of the scanner.

Portable user devices, such as smart phones and tablets, are more and more common, and include more and more features and functions. Such devices become more powerful and less battery intensive all the time, but still have relatively smaller computational resources and a constant concern over battery consumption rates.

Accordingly, there is a need for an improved functionality in highly mobile devices, and a need for a computationally efficient implementation of the improved functionality.

SUMMARY

The present disclosure provides systems, methods, and apparatuses for efficient texture comparison. A scannable object may be sensed and scanned. A map may be constructed based on the scan results. The map may be compared to one or more stored templates. Results of the comparison may be provided.

In some implementations, a secured processor may construct the map and may provide reduced resolution (and/or other versions that contain less information) versions of the map and/or the stored templates to one or more other processors. The one or more other processors may determine a match-set based on matching between the reduced resolution map and stored templates. The secured processor may then identify whether or not a match exists between the map and any stored template based on the match-set.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1** depicts a block diagram of a sample capacitive sensing array.

FIG. **2** depicts a sample electronic device incorporating the embodiment of a capacitive sensing array.

FIG. **3** is a cross-sectional view taken along line **4-4** of FIG. **2**, showing the embodiment of a capacitive sensing array incorporated into a stack-up with an input device.

FIG. **4** is an exemplary process for efficiently matching a scanned pattern according to one exemplary embodiment.

FIG. **5** is an exemplary system for efficiently matching a scanned pattern according to one exemplary embodiment.

FIG. **6** is an exemplary process for efficiently and securely matching a scanned pattern according to one exemplary embodiment.

DETAILED DESCRIPTION

Generally, embodiments discussed herein may provide efficient and secure texture sensing on a device, such as a smart phone. For example, a smart phone touch screen can be configured with a fingerprint sensor (e.g., a capacitive sensor) over part or all of the touch screen interface, the device housing, and/or other device inputs.

The present disclosure provides systems, methods, and apparatuses for efficient texture comparison. A scannable object may be sensed and scanned. A map may be constructed based on the scan results. The map may be compared to one or more stored templates. Results of the comparison may be provided. It should be appreciated that embodiments described herein may be used with any suitable fingerprint sensor, including swipe or strip sensors, two-dimensional array sensors, and the like.

In some implementations, a secured processor may construct the map and may provide reduced resolution (and/or other versions that contain less information) versions of the map and/or the stored templates to one or more other processors. The one or more other processors may determine a match-set based on matching between the reduced resolution map and stored templates. The secured processor may then identify whether or not a match exists between the map and any stored template based on the match-set.

FIG. **2** depicts an electronic device **200** that may incorporate a fingerprint sensor, e.g., a capacitive sensor. The electronic device may be a mobile telephone, a tablet computing device, a notebook computer, a personal digital assistant, a desktop computer, a portable media player, and the like. The sensor pad may be placed anywhere on device **200**, such as below an input mechanism, e.g., button **210**, an input and/or output mechanism, e.g., screen **220**, and/or a casing/housing, e.g., device housing **230** of the electronic device. The sensor may occupy part of an area (e.g., part of button **210**), a whole area (e.g., all of screen **220**), or an area that spans part/all of more than one of the areas. For example, a sensor may cover screen **220** and extend past the edge, covering all or part of forehead area **232** and/or chin area **234**. Essentially, any portion of the electronic device's enclosure may house the fingerprint sensor.

In certain exemplary embodiments, the device can include a separate attachment, such as external scan accessory **240**. Accessory **240** is shown connected to device I/O port **245**, which could be via a flexible wire connection, a ridged connection (e.g., simulating an extension of the device housing via a fastening mechanism (e.g., a snap together interface)). In other exemplary embodiments, this connection can be wireless via a proprietary protocol or a common protocol (e.g., Bluetooth, WiFi, GSM/CDMA/4G, etc.).

In certain exemplary embodiments, as mentioned above, the sensor may be included within the device housing, display, or other area, such as input button **210**. FIG. **3** illustrates one exemplary embodiment of a fingerprint scanner/sensor disposed beneath button **210**. FIG. **3** is a cross-sectional view of the electronic device of FIG. **2**, taken along line **4-4** of FIG. **2**, which may include the layers: cover dielectric **301**, ink **302**, liquid adhesive **303**, silicon TSV (3 um pass) **304**, solder **305**, flex **306**, air gap **307**, stiffener **308**, adhesive **309**, flex **310**, tact **311**, shim **312**, adhesive **313**, and bracket **314**. As shown in FIG. **3**, the fingerprint sensor chip (including both sensor pad and drive ring) may be positioned beneath the button (e.g., **210**), which may be the cover dielectric **301**. As illustrated, the top layer cover dielectric **301** is concave, as exemplary button **210** may be concave. A similar illustration, with differing dimensions and features, could show a flat screen in this layer extending to a housing, etc. In the exemplary embodiments of a button sensor, an ink layer and/or adhesive may be placed between the button's bottom surface and the sensor chip's top surface. The adhesive may bond the chip to the button, for example. One or more solder balls may affix the fingerprint sensor chip to a flex conductor. The solder balls may generally be placed near the center of the fingerprint sensor chip to reduce the likelihood of cracking due to stress.

The exemplary scanner shown in FIG. **3**, accessory **240**, and/or any other configuration incorporating a texture sensor/scanner with a user device may include a capacitive sensor (e.g., the same, similar, or different than the capacitive sensor shown in FIG. **1**), or any number of other types of sensors capable of sensing a texture/pattern of an adjacent or proximate object (e.g., an optical sensor) can be used in one or more exemplary embodiments.

Regardless of the location or configuration of the sensor, the exemplary device, including the exemplary sensor, can execute an exemplary process for matching a scanned texture with stored templates. FIG. **4** illustrates one such exemplary process. The exemplary process may start at **410** by sensing or detecting a scannable object. This may be a low power state, where power consumption is reduced while waiting for a sensed object. A scannable object can be one close to the device scanner or in contact with the device scanner. In other exemplary embodiments, the object may be “scannable” if it has a texture that can be detected, and in other exemplary embodiments an object may be scannable based on proximity, while the texture (or lack thereof) can be detected later in the exemplary process.

Once a scannable and/or proximate object has been detected, the exemplary process (e.g., using the exemplary device and sensor) can scan the object at **420**. The sensor results, which may vary depending on the type of sensor used (e.g., capacitive, optical, etc.), can then be used to construct a map associated with (e.g., descriptive of) the scanned features of the objects texture at **430**.

One such exemplary map can include a ridge flow map or direction map, which represents the direction of ridge flow within the scanned fingerprint image. As just one example of how a ridge flow map can be computed and stored: the exemplary map may contain a grid of integer directions, where each cell in the grid represents, e.g., an 8×8 pixel neighborhood in the image. Ridge flow angles can be quantized into, e.g., 16 integer bi-directional units equally spaced on a semicircle. In this example, starting with vertical direction 0, direction units can increase clockwise and represent incremental jumps of 11.25 degrees, stopping at direction 15 which is 11.25 degrees shy of vertical. Using this scheme, direction 8 is horizontal. A value of −1 in this map represents a neighborhood where no valid ridge flow was determined. Other exemplary methods of producing a ridge flow map are also possible, including different sizes, value ranges, matrix configurations, etc. Further, other map types are also possible, such as a quality map, contrast map, etc.

FIG. **5** shows an exemplary system that can be used to execute one or more exemplary processes. The exemplary system can include a sensor **540**, which can be sensor **100**, sensor **240**, the sensor of FIG. **3**, or any number of other exemplary sensors. This sensor can include a separate encryption/security feature/module (not shown) or send data to processor block **500** without a separate security module. The processor **500** can include an application processor (AP) **510** and a secure enclave processor (SEP) **520**. Each of these processors can include multiple processors, multiple cores, or reside on the same processor. The application processor **510** can be a general processor, responsible for several processing tasks of the device it resides within. The secure enclave processor **520** can be specially and/or specifically designed/configured to perform encrypted tasks, such as encrypting data associated with an authorized user's fingerprint/ID-pattern.

Processor block **500** can be connected to sensor **540** by any number or wired or wireless connections, using any number of transmission protocols, such as a serial peripheral interface (SPI). Processor block **500** can also be connected to a data storage repository **550**, which can include any number of mediums (e.g., magnetic material, solid state memory, etc.) Data repository **550** can include a secure data repository **555**, which can include encrypted data, e.g., data associated with an authorized user's fingerprint/ID-pattern. Secure repository **555** can be separate from the main repository **550** or a part of the main repository **550**. In the example of fingerprint patterns (e.g., maps based on a scanned fingerprint pattern), the repository can store files for multiple authorized users, files for multiple fingers (e.g., 10) of each user, multiple files for each finger, etc.

In a first exemplary operation, sensor **540** can scan a texture of an object. This texture can be translated into an associated map by sensor **540**, AP **510**, or SEP **520**. The SEP **520** can then retrieve encrypted templates (e.g., based on patterns associated with authorized users), and match the translated map with the encrypted templates. The SEP (e.g., via the AP, operating system (OS), and input/output devices (I/O)) can then provide a result, such as maintaining the screen lock (no match), or unlocking the device. Personal settings associated with the particular authorized user can also be pre-loaded at unlock.

The SEP **520** may have less computational resources than the more general processor AP **510**, and thus be some degree slower. In order to provide efficient and faster matching, certain exemplary embodiments may push some or all of the matching operations to the AP **510**. The AP **510** can identify a match and provide a result or identify the match so that a result can be provided. In one exemplary embodiments, the SEP **520** may decrypt the match templates and pass them to the AP **510** for match processing. While the SEP **520** may be needed for encryption/decryption (as AP **510** may be unsecured), the process can be greatly sped up, as the SEP **520** only has to perform tasks it was designed for (encryption/decryption), while the more powerful AP **510** can perform the more computationally intensive matching procedures.

A potential drawback of the above described exemplary embodiment can be that the AP **510** is unsecured or partially unsecured, and certain exemplary template maps may contain sufficient information that a malicious unauthorized user (e.g., someone who steals the device) could reverse engineer the exemplary template to construct a pattern that could unlock the device (e.g., sufficiently mimic an authorized user's fingerprint pattern). For example, an unauthorized user could intercept a decrypted template from the unsecured AP

510, and use the template data to construct an artificial object with associated properties (e.g. properties that when scanned would produce data that matched the intercepted template).

To overcome this potential security drawback, another exemplary embodiment of the present disclosure can include a process of collapsing the full maps into a sort of checksum, hash function, or histogram. For example, each encrypted ridge map template can have some lower resolution pattern computed and associated with the ridge map. One exemplary pattern could be a histogram of, e.g., the most common angles (e.g., a 2 dimensional (2D) array of common angles). The exemplary pattern could include in each slot an average value over a respective vector of the map. The exemplary pattern could include in each slot a sum of the values over a respective vector of the map. The exemplary pattern could include the smallest or largest value within a respective vector of the map, or could be a difference between a largest and a smallest value within the respective vector of the map. The exemplary pattern could simply be a particular vector, e.g., the pattern is merely the Nth vector of the map. Exemplary patterns can include more than one vector. For example, for an N by N map, the exemplary pattern could be the four edge vectors (e.g., the 1^{st} and Nth column, and the 1^{st} and Nth row), or any other sampling, positions, or calculated reduction. Numerous other exemplary embodiments are also possible, and any other exemplary pattern calculation can be used, where the exemplary pattern includes enough associated information to narrow the candidate list, while omitting enough associated information that the unsecured pattern cannot or cannot easily be reverse engineered into a matching texture.

In an exemplary process for this exemplary embodiment, a scanned object can have a ridge map calculated from the scanner input, e.g., in the SEP **520**. This encrypted ridge map can then have an unencrypted pattern calculated (according to the implemented protocol) and sent to the AP **510**. This pattern can be compared to patterns associated with the stored encrypted templates, which can be calculated in real-time or preferably be stored to reduce computation. Several of the templates may be different, but have the same or similar associated patterns, since two different templates may have values the same or similar in the areas used to determine the lower resolution patterns. Thus, the AP **510** may return multiple positive results (and might also return a single match or no matches as determined with the scanned pattern to be compared). The SEP **520** can then access the encrypted ridge maps associated with any patterns identified by the AP **510** as matching. The SEP **520** can then compare the ridge map of the scanned pattern with the small subset of possible matches, instead of the entire library of possible matches. This exemplary embodiment can therefore greatly speed up the computation of map matching by leveraging the powerful AP, while maintaining encrypted security of the stored ridge maps.

As mentioned earlier, any number of other exemplary embodiments are also possible, and the above example is presented with certain specific implementations (e.g., using ridge maps for patterns) for illustration purposes, but could be applied to any number of other exemplary embodiments having other exemplary implementations.

FIG. **6** illustrates an exemplary embodiment of this exemplary process. At **610**, the exemplary process can sense or detect an object to scan. At **620** the exemplary process scans the object. Secure process **604** then constructs an input map based on the scan results at **630**. The secure process **604** can then construct a lower resolution pattern **635**. Secure process **604** can then load, determine, or otherwise provide stored template patterns (associated with stored template maps) and the input pattern to a process **602**, which can be unsecured, partially secured, secured with a different protocol, or secured in the same manner as process **604**. Process **602** can then run a match comparison of the input pattern and the received template patterns at **650**. At **655**, process **602** can provide the identity of possible match results to secured process **604**. This can be a pointer, an identification, or the actual matching pattern. The secure process **604** can then run (e.g., at **660**) a full match comparison of the input map and the stored templates associated with those possible matches identified at **655**. Finally, the exemplary process can provide the results at **670**.

Although embodiments have been described herein with respect to particular configurations and sequences of operations, it should be understood that alternative embodiments may add, omit, or change elements, operations and the like. Accordingly, the embodiments disclosed herein are meant to be examples and not limitations.

I claim:

1. A device, comprising:

at least one encrypted processor that is configured to determine an input map associated with a texture pattern and calculate a reduced resolution pattern based on the input map, and calculate one or more reduced resolution template patterns, each reduced resolution template pattern based on a respective stored encrypted template map; and

at least one unsecured processor, communicably connected to the at least one encrypted processor, that is configured to:

receive the reduced resolution pattern and the one or more reduced resolution template patterns and identify a match-set if a match exists between the reduced resolution pattern and at least one reduced resolution template pattern, wherein the at least one encrypted processor is further configured to receive the match-set and identify if a match exists between the input map and any stored encrypted template map that is associated with the match-set.

2. The device of claim **1**, wherein the match-set includes an identity of each reduced resolution template pattern that matches the reduced resolution pattern or an identify of each stored encrypted template map associated with each reduced resolution template pattern that matches the reduced resolution pattern.

3. The device of claim **1**, wherein the at least one second processor is configured to identify a plurality of possible matches.

4. The device of claim **1**, wherein the at least one second processor is faster than the at least one encrypted processor.

5. The device of claim **1**, wherein at least one of:

the reduced resolution pattern comprises at least one of a checksum generated from the texture pattern, a hash generated from the texture pattern, or a histogram generated from the texture pattern; or

each reduced resolution template pattern comprises at least one of a checksum generated from the respective associated stored encrypted template map, a hash generated from the respective associated stored encrypted template map, or a histogram generated from the respective associated stored encrypted template map.

6. The device of claim **1**, wherein the reduced resolution pattern includes sufficient information to identify a match-set between the reduced resolution pattern and the one or more reduced resolution template pattern patterns but not sufficient information to determine the input map from the reduced resolution pattern.

7. The device of claim **1**, wherein each reduced resolution template pattern includes sufficient information to identify a match-set based on comparison of the reduced resolution pattern and the reduced resolution template pattern but not sufficient information to determine the respective associated stored encrypted template map.

8. The device of claim **1**, further comprising at least one device scanner, communicably connected to the at least one encrypted processor that obtains the texture pattern by scanning at least one scannable object.

9. The device of claim **8**, wherein the at least one scannable object comprises at least one fingerprint.

10. A method, comprising:

determining, utilizing at least one secure processor, an input map based on a scan input, wherein the scan input is associated with a texture pattern;

calculating a reduced resolution pattern, utilizing the at least one secure processor, based on the input map;

calculating one or more reduced resolution template patterns, utilizing the at least one secure processor, wherein each reduced resolution template pattern is based on a respective encrypted template map;

providing the reduced resolution pattern and the one or more reduced resolution template patterns to at least one general processor utilizing the at least one secure processor;

receiving, utilizing the at least one secure processor, a match-set identified by the at least one general processor if a match exists between the reduced resolution pattern and at least one reduced resolution template pattern; and

identifying, utilizing the at least one secure processor, whether a match exists between the input map and any encrypted template map that is associated with the match-set.

11. The method of claim **10**, further comprising determining, utilizing the at least one general processor, whether the reduced resolution pattern matches at least one of the one or more of reduced resolution template patterns.

12. The method of claim **10**, further comprising receiving the scan input utilizing the at least one secure processor.

13. The method of claim **10**, further comprising providing a result based on determining if the input map matches one or more of the template maps utilizing the at least one secure processor.

14. The method of claim **10**, wherein at least one of:

the reduced resolution pattern comprises at least one of a checksum generated from the texture pattern, a hash generated from the texture pattern, or a histogram generated from the texture pattern; or

each reduced resolution template pattern comprises at least one of a checksum generated from the respective associated template map, a hash generated from the respective associated template map, or a histogram generated from the respective associated template map.

15. The method of claim **10**, wherein the reduced resolution pattern includes sufficient information to identify a match-set between the reduced resolution pattern and the one or more reduced resolution template patterns but not sufficient information to determine the input map from the reduced resolution pattern.

16. The method of claim **10**, wherein each reduced resolution template pattern includes sufficient information to identify a match-set based on comparison of the reduced resolution pattern and the reduced resolution template pattern but not sufficient information to determine the respective associated template map.

17. The method of claim **10**, further comprising:

sensing for at least one scannable object; and

obtaining the scan input by scanning the at least one scannable object.

18. The method of claim **17**, wherein the at least one scannable object comprises at least one fingerprint.

19. The method of claim **10**, wherein the match-set includes an identity of each reduced resolution template pattern that matches the reduced resolution pattern or an identify of each template map that is associated with each reduced resolution template pattern that matches the reduced resolution pattern.

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